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HIGH ALTITUDE VEHICULAR EMISSION CONTROL PROGRAM

VOLUME VII. EXPERIMENTAL CHARACTERIZATION OF VEHICULAR EMISSION AND ENGINE DETERIORATION

AUTOMOTIVE TESTING LABORATORIES,
INCORPORATED

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

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HIGH ALTITUDE VEHICULAR EMISSION CONTROL PROGRAM

VOLUME VII. EXPERIMENTAL CHARACTERIZATION OF VEHICULAR EMISSION AND ENGINE DETERIORATION

INTERIM REPORT

JULY 1974

PREPARED FOR:

STATE OF COLORADO
DEPARTMENT OF HEALTH
DENVER, COLORADO 80220

ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
DENVER, COLORADO 80203

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TRW / ENVIRONMENTAL SERVICES

DISCLAIMER

This report was developed for the Environmental Protection Agency and the State of Colorado by TRW and ATL under contract numbers 68-02-1385 and C290526. The contents of this report are reproduced herein as received from the contractor. The opinions, findings, and conclusions are those of TRW and ATL and are not necessarily those of the sponsoring agencies. Mention of company or product names does not constitute endorsement by either the Environmental Protection Agency or the State of Colorado.

The results and conclusions presented are based on the preliminary data developed from the first six months of the ongoing deterioration test program (conducted by Automotive Testing Laboratories). The extent to which these data are not representative of the vehicle population in the Denver area, however, could have a significant impact on the resultant conclusions and recommendations.

PREFACE

This report, "High Altitude Vehicular Emission Control Program," consists of seven volumes. Listed in the following are the subtitles given for each volume:

- Volume I - Executive Summary, Final Report, January 1974.
- Volume II - Experimental Characterization of Idle Inspection, Exhaust Control Retrofit and Mandatory Engine Maintenance, Final Report, December 1973.
- Volume III - Impact of Altitude on Vehicular Exhaust Emissions, Final Report, December, 1973.
- Volume IV - Analysis of Experimental Results, Final Report, December 1973.
- Volume V - Development of Techniques, Criteria and Standards to Implement a Vehicle Inspection, Maintenance and Modification Program, Final Report, December 1973.
- Volume VI - The Data Base, Final Report, January 1974.
- Volume VII - Experimental Characterization of Vehicular Emission and Engine Deterioration, Interim Report, June 1974.

The first volume summarizes the general objectives, approach and results of the study. The second volume presents a detailed description of the experimental programs conducted to define the data base. Volume III reports the methods and analysis used in developing the basic relationships between mass emissions and altitude. A quantitative analysis of the results from the experimental program is presented in Volume IV. The fifth volume provides an analysis of the techniques and criteria required in establishing a vehicle emission control program for the Denver area. The actual data base developed from the experimental

program is given in Volume VI. Lastly, Volume VII reports the results of the six month deterioration program.

The work presented herein is the product of a joint effort by several consulting firms. Automotive Testing Laboratories (ATL) was responsible for the design and implementation of the basic experiments. TRW provided the data management and analysis of the experimental results.

ACKNOWLEDGEMENTS

TRW would like to acknowledge the efforts extended by the Colorado State Department of Health and Region VIII of the Environmental Protection Agency.

The contributions of Messrs. Don Sorrels and Robert Taylor of the Colorado State Department of Health were of particular significance.

Mr. Dale M. Wells of Region VIII served as Project Officer.

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1.0 SUMMARY AND CONCLUSIONS

This report highlights the findings from the first phase (six months) of the high altitude emission deterioration program. The deterioration data presented herein reflects the results from both the idle inspection and mandatory maintenance programs.

- Six months of emission data is insufficient to characterize the overall effect of engine deterioration.
- Vehicle attrition and unauthorized maintenance has had a significant impact on determining the actual effect of engine deterioration.
- Approximately one-third of the vehicles initialized were unavailable for recall at the end of six months.
- A substantial level of unauthorized maintenance, on the order of 25 percent, occured for both the idle inspection and mandatory maintenance fleets.
- The potential impact of increased vehicle attrition and unauthorized maintenance may preclude developing statistically significant estimates of engine deterioration during the next six month period.
- An expanded experimental program may be necessary to fully evaluate the actual effects. Another alternative would be to take an emission surveillance "snapshot" of the vehicle population on a periodic basis in order to observe general emission deterioration trends.
- A program to better characterize the nature and extent of unauthorized maintenance is required.
- In general, vehicular emission levels (as measured in CVS units) did not show a statistically significant increase over the six month period. One exception occured for the mandatory maintenance fleet. Here, HC emissions increased to a value larger than the original "as received" state. This can be attributed to the small sample size and the high incidence of ignition misfire within this population segment.
- On the average, idle HC and CO rejection rates at six months (using the 50 percent failure criteria) were lower than for the pre-maintenance vehicle population.

- Deteriorated emission levels need to reach approximately 80 percent of the "as received" values in order to show a statistically significant difference from the post-tuned emission state.

- Regression analysis indicated that accumulated mileage over the six month period could not explain the observed rate of engine deterioration. A larger sample size might reveal better correlations between these two variables.

- The emission levels for the idle inspection and mandatory maintenance fleets showed a statistical difference for both the post-maintenance and post-deteriorated states. This can be attributed primarily to the effect of maintenance and the fact that the mandatory fleet contained somewhat newer vehicles.

2.0 INTRODUCTION

A basic unknown in evaluating the cost-effectiveness of vehicular inspection/maintenance is the extent and characteristics of emission deterioration. Studies conducted by TRW have shown that emission deterioration can have a substantial effect on the effectiveness of the selected procedure (e.g., idle inspection).* In an attempt to assess the potential impact of emission deterioration at altitude, an experimental test program was undertaken using approximately 250 vehicles. The project was designed to characterize emission deterioration and engine degradation for vehicles operating in the greater Denver area. The project, involving the re-test of vehicles available at the conclusion of two consecutive six month intervals recently progressed beyond mid-point. This interim report presents a detailed analysis of the results from the six month engine deterioration and degradation study.

The primary objective of this study was to develop emission deterioration factors which are to be utilized to evaluate the long term benefits of a mandatory idle inspection and maintenance program and of a mandatory engine maintenance program. A secondary object is to determine the extent of owner tampering, including its impact upon the effectiveness of an inspection/maintenance program, and to determine possible legislative requirements to maintain overall effectiveness of a mandatory program.

The preceeding section (Section 1.0) has provided a summary of the conclusions and recommendations synthesized from the study. This section (Section 2.0) focuses on the background of the test program

* TRW, CAPE-13-68 Research Program (1972).

and presents a summary of the basic experimental objective. Section 3.0 outlines ATL's laboratory procedures and TRW's data management system. Section 4.0 summarizes a comparison of the two programs as well as discusses the extent and impact of unauthorized maintenance. Section 5.0 [highlights the results for the idle inspection and mandatory maintenance programs]. This analysis includes frequency histogram plots of pre and post deterioration CVS emissions, statistical regression evaluation, and a variety of other statistical assessments.

3.0 PROCEDURES DEVELOPMENT

3.1 PROGRAM DESIGN

The program was designed to utilize a preconditioned and pretested sample of vehicles from which various data, pertinent to program objectives, could be obtained.

A sample of three-hundred 1964 through 1973 model-year vehicles, selected to represent that segment of the Colorado light-duty vehicle (under 6000 lbs GVW) population, were used initially to evaluate idle inspection and maintenance, emission control retrofit and mandatory engine maintenance. This segment represented about 90% of the light-duty vehicle population. All vehicles in the sample were initially subjected to inspection and maintenance. Idle emission inspections were performed at ten selected state licensed motor vehicle safety inspection stations. Station personnel were trained in advance and were required to perform inspection and maintenance of vehicles in accordance with specific procuedures. All vehicles were laboratory tested in the as-received condition before delivery to the stations. Vehicles which failed station inspection and were subsequently repaired were re-tested by laboratory procedures to determine the effectiveness of station performance. A segment of the vehicle sample was then utilized to evaluate emission control retrofit and modified tune-up specifications. *

* A more complete description of the basic test procedures can be found in Volume II of this report.

Although three-hundred vehicles comprised the initial sample, the potential size of the sample available for re-test was reduced to about two-hundred and fifty vehicles.* This reduction, numbering about fifty vehicles, came about as a result of an initial loss of several vehicles which had been tested and released to owners prior to start-up of the deterioration study. A number of other vehicles comprising the initial sample were determined to be unsuitable for deterioration study purposes for various other reasons.

During the time interval following initial testing, vehicles comprising the test sample were presumably operated in a typical manner although several existing factors undoubtedly had some impact on mid-point results. Weather conditions during the interval (August, 1973 through May, 1974), for example, were for the most part seasonably cold and presumably had an indirect effect on engine warm-up characteristics, mileage accumulation and maintenance requirements. Additionally, the fuel crisis and attendant factors, were predominant throughout much of the study interval and are believed to have potentially biasing effects on study results by altering mileage accumulation patterns, fuel preference and overall vehicle useage. The effects of these variables are virtually impossible to evaluate. In any case, however, the project proceeded according to design.

In planning for the interval which followed initial testing, procedures for handling test vehicles exhibiting undesirable operating characteristics or component failure were devised. A maintenance

* Of the original 250 vehicles, 150 were assigned to the idle inspection fleet and 100 to the mandatory maintenance fleet. These initial group sizes were reduced (the results of attrition) to 87 and 78 vehicles, respectively.

committment was established and communicated to the vehicle owner. A vehicle prematurely returned to the laboratory for repair work was subjected to an on-the-spot inspection to establish the validity of a request for repair. In certain situations, owner dissatisfaction with some aspect of vehicle performance proved to be unfounded. In other situations, a legitimate requirement for maintenance did in fact exist. In the latter case, a loan car was issued and the test vehicle was retained for further testing and maintenance. In this case, a series of tests, identical to those performed initially, was conducted, repairs to the vehicle were completed and the vehicle was returned to its owner. Data developed as a result of these procedures were retained for subsequent processing and reporting.

As reported earlier, two hundred and fifty vehicles of the original sample were judged suitable for retest. It was originally anticipated that a significant number of vehicles would be lost to the program for various reasons including transfer of ownership, owner relocation, accidents and negative owner reaction or loss of interest. In this respect an attrition rate of 40 percent was allowed.

After the nominal interval of six months had elapsed, vehicles were recalled for deterioration and degradation testing. An attempt to maintain an initial tolerance of 180 $\pm$ 5 days proved to be impractical. The tolerance was subsequently relaxed to 180 $\pm$ 10 days to maintain a high retest rate.

At the appropriate time, one or more attempts to contact owners whose vehicles qualified for retest were made. As anticipated, a significant number of owners had moved outside the area, had sold the

test vehicles, had expressed disatisfaction with some aspect of the program or had simply become disinterested. On the other hand, a significant number of vehicles remained available. The remaining vehicles, numbered at 165, were recalled and retested. Testing procedures, identical to those performed initially, were then applied. At test completion seals applied to engine adjustments and identification marks applied to emission related components were inspected and the incoming status of each adjustment and component part was recorded. Data were then processed and compiled.

Through the retest phase of the program laboratory instrumentation and equipment calibration and operating procedures were maintained in accordance with standards applied in the initial program. Quality control tolerances were similarly maintained and procedures relating to data auditing were applied.

3.2 TEST VEHICLES

Three hundred vehicles were initially selected and utilized to represent the 1964 through 1973 Colorado motor vehicle population. Approximately two hundred and fifty were prepared for the deterioration study phase. As anticipated, a significant level of attrition occured during the six month period and one-hundred and sixty-five vehicles were actually submitted for retest.

3.2.1 Vehicle Sample Composition

Table 1 shows the distribution of vehicles subjected to retest.

TABLE 3-1

DISTRIBUTION OF SAMPLE AFTER 6 MONTHS

	Model-Year										
	73	72	71	70	69	68	67	66	65	64	Total
Make											
Ammo	0	1	1	1	0	1	0	1	0	1	6
Buic	0	0	1	0	0	2	1	0	1	1	6
Cadi	0	0	0	1	0	0	0	0	2	0	4
Chev	6	4	3	3	2	2	5	5	5	5	40
Chry	0	1	1	1	0	0	1	1	0	0	5
Dodg	1	1	0	1	1	1	1	1	0	1	8
Ford	4	4	6	3	2	4	6	5	7	2	43
Merc	0	1	0	0	1	1	1	0	1	0	5
Olds	1	0	0	1	0	1	1	1	1	1	7
Plym	1	3	1	2	2	1	1	1	0	1	13
Pont	1	1	1	1	1	0	3	2	2	0	12
Volk	0	1	1	2	0	2	0	2	1	0	9
Toyo	1	0	1	1	1	0	0	0	0	0	4
Dats	0	0	1	0	0	0	0	0	0	0	1
Opel	1	1	0	0	0	0	0	0	0	0	2
Total	16	18	17	17	10	15	20	18	20	14	165

In comparison of the initial sample (Table 2. Volume II) versus the sample shown in Table 3-1 above, it can be seen that the retested sample approximates the initial sample by a factor of 0.5 by both make and model-year. From this comparison it can be concluded that the retested sample approximates the distribution of light-duty vehicles in Colorado.

3.2.2 Vehicle Preparation and Handling

Upon receipt of the vehicle for retest, an inspection of the vehicle exterior, interior and exhaust system was performed to determine incoming status. A loan car was issued to replace the test vehicle and the necessary vehicle agreement forms were completed.

The vehicle was then moved to the laboratory for temperature soaking prior to emission testing and engine inspection.

After a minimum soak period of twelve hours, the vehicle fuel supply system was disconnected and reconnected to a laboratory fuel supply system. A batch of summer-grade fuel, utilized for initial testing had been retained and was used to perform the retests. Emission tests were then performed, the vehicle was relocated to another area in the laboratory and a inspection of engine components and adjustments was completed. The vehicle was then returned to its owner.

3.3 LABORATORY TESTING AND EVALUATION

Procedures employed for retest were identical to those applied initially.

3.3.1 Exhaust Emission Testing Procedures

Laboratory standard exhaust emission tests were performed in accordance with procedures outlined in Federal Register, Volume 3B, Number 124, Part III, dated June 28, 1973. Standard tests were preceeded by a minimum 12 hour temperature soak at laboratory ambient conditions (68^{o} F to 72^{o} F).

Key mode tests were performed in accordance with procedures outlined by Clayton Manufacturing Company of El Monte, California. Key mode testing and resulting data have no direct bearing on the objectives of this phase of the study but were included in the test procedure merely to expand the data base.

Idle emission testing was performed in conjunction with key mode testing. Emission samples were taken at no load conditions of curb idle (Drive gear for automatic transmission equipped vehicles) and

2500 engine rpm. Instrumentation and operating procedures were identical to those employed during the initial phase of testing. Both laboratory garage-type inspection equipment (listed in Table 5 of Volume II) were employed.

Instrument and equipment calibrations established in the initial testing phase were maintained throughout the retest interval. Analytical system calibrations were established using an inventory of EPA named gases. Flow calibration of the CVS was verified using the laminar flow element with calibration traceable to the National Bureau of Standards. Dynamometer calibrations were established and verified on a regular basis using the coast-down technique. In addition, propane recovery tests, NOx converter efficiency checks and analytical system leak checks were performed on a daily basis.

3.3.2 Engine Diagnostic Procedures

Diagnoses of engine conditions were performed at two points in the overall vehicle procedure. During key mode operations on the chassis dyanamometer the laboratory analytical system recorders were operational for a period of about one minute. During this interval and during periods of speed changes, emission traces were observed for an indication of malfunction evidenced by abnormally high hydrocarbon (HC) or carbon monoxide (CO) levels. The HC trace also provided an indication of ignition system mis-fire. Observations were recorded. Oxides of nitrogen (NOx) emission controls on applicable vehicles were also inspected for proper operation during key mode testing. A fully operational system was indicated by the absence of vacuum to the distributor at low cruise conditions and the presesence of vacuum to the distributor at high cruise conditions. The

second point at which diagnostic procedures were applied was immediately after dynamometer tests were completed. The vehicle was removed from the dynamometer area and a more extensive diagnostic procedure was applied. Concurrently, the inspection to determine the extent of tampering and alteration or replacement of parts was performed.

3.4 DATA PROCESSING AND MANAGEMENT

The combination of a large data base, and the necessity of a series of complex operations involved in the analysis, necessitated the use of a computerized data management system.

The data collected from the deterioration experiment has been stored as a working file on the CDC 6500 disk pack. More permanent copies of the data base are also stored on a magnetic tape and on card files. Extensive computer software was utilized in managing and processing the data. The following data management activities were performed by TRW:

- retrieval and sorting of data
- development of graphic presentations
- statistical analysis

A brief description of each of these data management functions is presented in the subsequent paragraphs.

Retrieval and Sorting of Test Data

The principal data handling program in the data management system, DETER, serves as the basic interface between the data base and other software. This program retrieves the selected data from disk storage and sorts it by a number of classification systems. The data can be culled in the following ways:

- CVS emissions
- Key modes
- Engine parameters
- Vehicle characteristics

1) the total population
2) sort by age group
3) sort by manufacturer
4) sort by make, within a manufacturer
5) sort by engine size group
6) sort by weight group
7) sort by PASS/FAIL at idle inspection

Graphic Presentation

One major element of the data analysis activity was to summarize information in the form of frequency histograms. Two programs are used to preform the retrieval and plotting functions. DETER is used to retrieve data records for the requested plot, sort the data, and write a data input file for the plotting routine. HISTM provides histogram frequency plots of the data. The plots are drawn on by a CalComp plotter from a tape written by HISTM.

Statistical Analysis

Two main statistical packages were used in processing the data relevant to the engine deterioration study.

The data handling program DETER had basic statistical capabilities built into it. It computes means, standard deviations, T-scores, and CVS emission deterioration factors.

The DETER program also is used to create an input file for the other statistical applications program (TSTAGE). The TSTAGE program performs ordinary least squares regressions. Equations were derived for the deterioration of the three CVS mass emissions (HC, CO, NOx) as functions of the odometer readings. Dummy variables were exploited

to yield independent equations for the different sort groups (i.e., age group). T-scores, F-values, and R^2 computations were all carried out in an effort to determine statistical significance.

4.0 BASIC EXPERIMENTAL RESULTS

This section presents the basic experimental results developed from the first six months of the deterioration program. The analysis focuses on the extent and frequency of unauthorized maintenance that occured during the program. In addition, an assessment is made of the potential differences between the two test fleets.

4.1 UNAUTHORIZED MAINTENANCE

During the course of this study it was necessary to return the test vehicles to their owners for a deterioration period of six months. Before this was done, key engine components were marked so that unauthorized maintenance performed upon them could be detected during the subsequent re-inspection. Once the vehicles were recalled an inspection was performed to determine the state of the engine system. This inspection provided a direct means for assessing the extent of unauthorized maintenance. The results from this inspection are summarized in Table 4-1. Fully twenty-five percent of the vehicles were subject to unauthorized maintenance during the six month deterioration period. In general, the incidence of unauthorized maintenance appears uniformly consistent. Spark plugs and air filters represented two of the more frequently changed components for both vehicle fleets. This situation is somewhat surprising in the case of the mandatory maintenance population because all vehicles in that group underwent a thorough engine tune-up. The repair of other ignition oriented components (e.g., wire, coil) may relate strongly to the high level of ignition misfire detected in the vehicle population (15 percent versus 5 percent at sea level). Clearly, the extent of

TABLE 4-1

SUMMARY OF UNAUTHORIZED MAINTENANCE

TAMPERED ITEM	IDLE INSPECTION NUMBER	IDLE INSPECTION PERCENT	MANDATORY MAINTENANCE NUMBER	MANDATORY MAINTENANCE PERCENT
IGNITION WIRES	5	6	3	4
COIL	0	0	2	3
SPARK PLUGS	7	9	6	8
AIR FILTER	12	14	7	9
FUEL MIX. SCREWS	1	2	2	3
IDLE ADJUST. SCREWS	4	5	3	4
CHOKE SETTING	4	5	4	6
DIST. ADJ. SCREW	4	5	3	4
POINTS ADJ. SCREW	4	5	5	7
CONDENSER	4	5	4	6
ROTOR	4	5	3	4
DISTRIBUTOR CAP	5	6	6	8
PCV	3	4	2	3
TOTAL CARS TAMPERED	23	27	19	25
SAMPLE SIZE	(87)		(78)	

unauthorized maintenance observed in this experiment underscores the need for the development of procedures for controlling this phenomena in the general population. A study program to more fully evaluate the possible effects of unauthorized maintenance on the operational effectiveness of the posed idle inspection program appears warranted. Because of the possible bias of including vehicles which receive unatuhorized maintenance, results were calculated for both the total population and for those vehicles which had not received additional maintenance.

4.2 COMPARISON OF MANDATORY MAINTENANCE REGIME AND IDLE INSPECTION REGIME

To reasonably compare the data for the two maintenance programs it must first be determined whether the vehicles in the two fleets come from the same population or indeed were different. Tables 4-2 and 4-3 summarize T-scores for the two populations for the following three states: pre-maintenance, post-maintenance, and post deterioration. These results are reported by control type. The analysis that follows will be based upon Table 4-3 containing just those vehicles not subjected to unauthorized maintenance. The T-scores imply that HC and NOx emissions were comparable before maintenance, while CO emissions were not.* Post-maintenance T-scores reveal that at that time, emissions were significantly different between the two regimes.

---

* A T-score greater than unity indicates that a statistical difference exists between the two populations.

TABLE 4-2

ESTIMATED T-SCORES FOR MAINTENANCE REGIMES FOR TOTAL POPULATION

MODE	PRE-MAINTENANCE	POST-MAINTENANCE	POST-DETERIORATION
	PRECONTROL VEHICLES		
HC	1.217	0.856	3.876
CO	1.886	1.768	2.057
NO_x	1.075	1.333	1.955
SAMPLE SIZES (I/M) (M/M)	(49) (23)	(49) (23)	(49) (23)
	CONTROLLED VEHICLES		
HC	0.281	1.643	0.509
CO	0.104	1.653	1.332
NO_x	0.798	1.680	1.027
SAMPLE SIZES (I/M) (M/M)	(38) (55)	(38) (55)	(38) (55)

TABLE 4-3

ESTIMATED T-SCORES FOR MAINTENANCE REGIMES WITH UNAUTHORIZED MAINTENANCE ELIMINATED

MODE	PRE-MAINTENANCE	POST-MAINTENANCE	POST-DETERIORATION
	PRECONTROL VEHICLES		
HC	0.466	1.001	3.395
CO	1.664	1.812	2.155
NO_x	0.909	0.687	1.096
SAMPLE SIZES (I/M) (M/M)	(37) (14)	(37) (14)	(37) (14)
	CONTROLLED VEHICLES		
HC	0.791	1.822	0.447
CO	1.575	2.491	2.289
NO_x	0.454	1.299	0.998
SAMPLE SIZES (I/M) (M/M)	(27) (45)	(27) (45)	(27) (45)

The important factor for this study is the post-deterioration emissions differences.

For precontrol vehicles, HC emissions are significantly greater for the mandatory maintenance fleet vis-a-vis the idle inspection fleet, but the small sample size (14) must be taken into account in analyzing this result. CO emissions cannot be reasonably compared because of the two different populations. NOx emissions are slightly greater for the idle inspection procedure.

For controlled vehicles HC and NOx emissions reveal themselves to be not statistically different to a significant extent. CO emissions cannot be reasonably compared. In summary, the emissions from the two fleets for both the post-maintenance and post-deteriorated states are different. Part of this difference can be attributed to the higher attrition level of lower emitting vehicles in the mandatory fleet and to the level of maintenance received.

5.0 IMPACT OF DETERIORATION ON ALTERNATIVE PROGRAMS

5.1 IDLE INSPECTION AND MAINTENANCE

This section examines the impact of engine and emission deterioration on both the idle and mandatory maintenance programs. The evaluation provides both histograms and statistical analysis of the developed results.

The idle inspection and maintenance procedure, as detailed in Volume IV, consisted of an initial examination of the key modes idle HC and idle CO. If the vehicle conformed to the prescribed standards (see Table 5-1) it was left untouched, however, if it failed, a systematic program of engine maintenance was performed.

This discussion focuses on an evaluation of the potential impact of emission deterioration on the idle inspection procedure. In particular, analyses have been performed in the following areas:

- pre and post maintenance vehicles remaining after six months
- pre and post deterioration emission frequency distributions
- idle mode failure rates
- factors influencing deterioration
- levels of statistical significance
- comparison of maintenance and non-maintained fleets

A brief review of the CVS mass emission results for the idle inspection and maintenance program is given in Table 5-2 for the 87 vehicles remaining in the idle test fleet. These results do not appear substantially different than the ones developed during the initial test phase for the fleet of 300 vehicles. The trends reflected in the preceeding results also hold when vehicles that have received unauthorized maintenance have been removed from the fleet.

TABLE 5-1

IDLE INSPECTION PASS/FAIL CRITERIA

Measurement	Criteria	
	Pre-Controlled	Controlled
1. Idle HC	800 ppm	330 ppm
2. Idle CO	6%	4%

TABLE 5-2

IDLE INSPECTION CVS EMISSIONS PRE AND POST MAINTENANCE

MODE	PRE-MAINTENANCE MEAN (GR/MI)	PRE-MAINTENANCE STD. DEV.	POST-MAINTENANCE MEAN (GR/MI)	POST-MAINTENANCE STD. DEV.	DIFFERENCE (PERCENT REDUCTION)	T-SCORE
HC	8.18	5.38	6.99	3.57	14.5	1.79
CO	111.80	51.57	101.12	47.37	9.6	1.56
NO_x	2.64	1.42	2.60	1.41	1.5	-0.24

SAMPLE SIZE = 87

UNAUTHORIZED MAINTENANCE ELIMINATED

HC	7.73	4.39	6.73	2.76	12.9	1.54
CO	103.95	43.51	96.51	44.95	7.2	1.15
NO_x	2.70	1.35	2.63	1.42	2.6	0.46

SAMPLE SIZE = 64

Subsequent to a series of post-maintenance tests the vehicles were returned to their owners for a six month deterioration period. The cars were retested within a period equal to 180 $\pm$ 10 days of the post maintenance inspection. From Table 5-3 it can be seen that HC and CO emissions increased over the deterioration period, but the change is statistically insignificant, as witnessed by the low T-scores.* NOx emissions decreased slightly over the six month period, but this decrease is also statistically insignificant.

Figures 5-1 to 5-6 illustrates the shift in emissions over the six month period for HC, CO and NOx, respectively. While both pre-deterioration (unhatched bars) and post deterioration (hatched bars) results show log-normal distributions (a distribution which is skewed to the left with an extended tail to the right), the distribution for the post deterioration emissions is shifted to the right with respect to the distribution of the pre deterioration emissions, thus signifying higher average emission levels. While these frequency plots do not "prove" the significance of observed emission deterioration they do present an indication of general trends. It should be further noted that as a result of the log-normal distributions of the emissions (as opposed to a normal or "bell-shaped" distribution) a majority of the vehicles in any one population will emit at a lower level than the mean level for that population. This results from the skewed shape of the distribution.

* Typically, a T-score of less than one is not considered to yield statistically significant results (i.e., the difference between the two samples is not real).

TABLE 5-3

IDLE INSPECTION CVS EMISSIONS PRE AND POST DETERIORATION

MODE	PRE-DETERIORATION MEAN (GR/MI)	PRE-DETERIORATION STD. DEV.	POST-DETERIORATION MEAN (GR/MI)	POST-DETERIORATION STD. DEV.	DIFFERENCE (GR/MI/ 1000 MI)	DIFFERENCE (GR/MI/ MONTH)	T-SCORE
HC	6.99	3.57	7.50	4.07	0.13	0.09	0.83
CO	101.12	47.37	105.79	51.93	1.16	0.79	0.61
NO_x	2.60	1.41	2.54	1.40	-.01	-0.01	-0.44

SAMPLE SIZE = 87

UNAUTHORIZED MAINTENANCE ELIMINATED

HC	6.73	2.76	7.49	4.33	0.19	0.13	0.84
CO	96.51	44.95	99.74	44.95	0.80	0.55	0.42
NO_x	2.63	1.42	2.57	1.42	-0.02	-0.01	-0.40

SAMPLE SIZE = 64

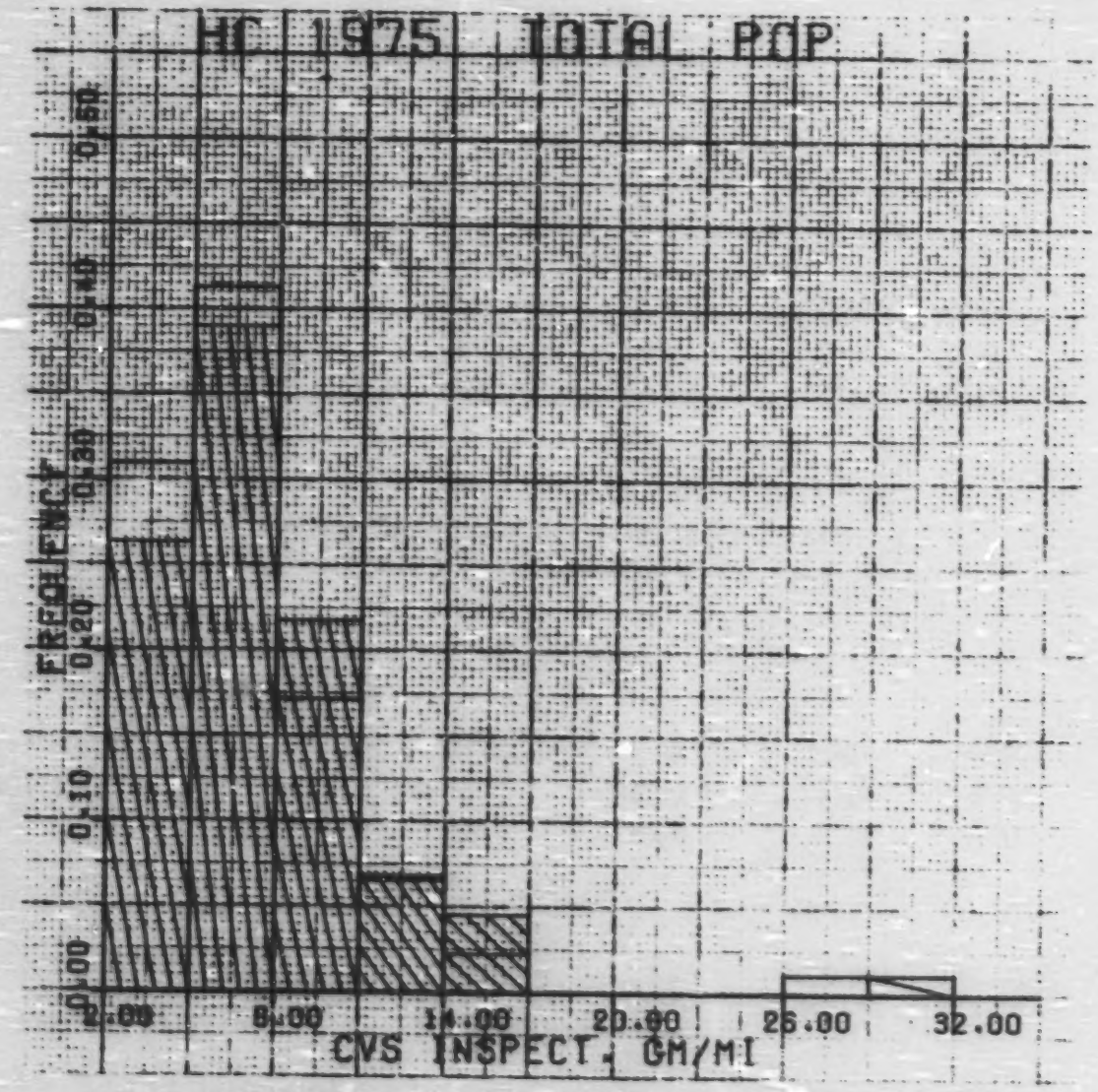

Figure 5-1 HC Histogram For Idle Inspection Pre and Post Deterioration for Total Population

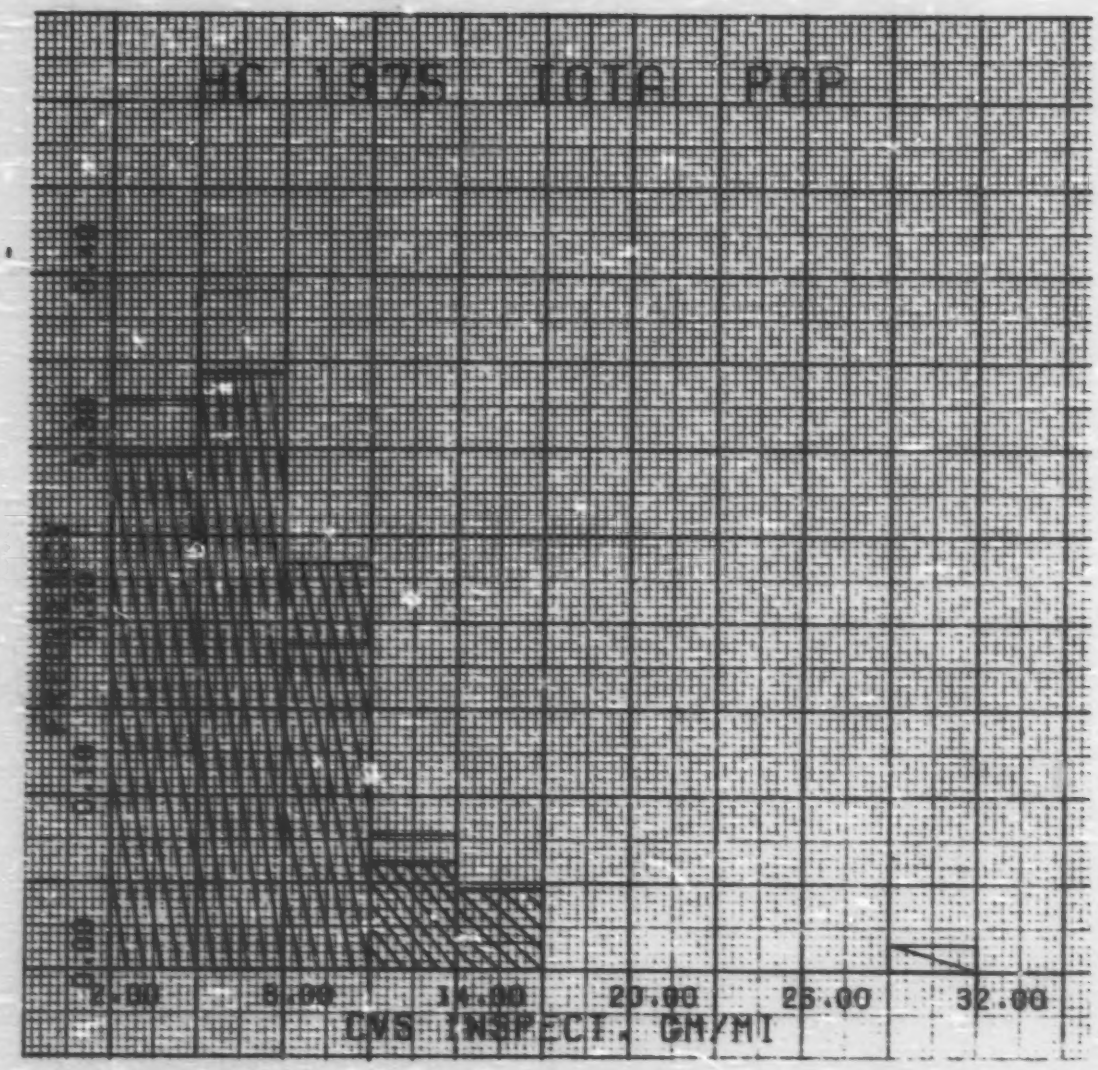

Figure 5-2 HC Histogram for Idle Inspection Pre and Post Deterioration with Unauthorized Maintenance Eliminated

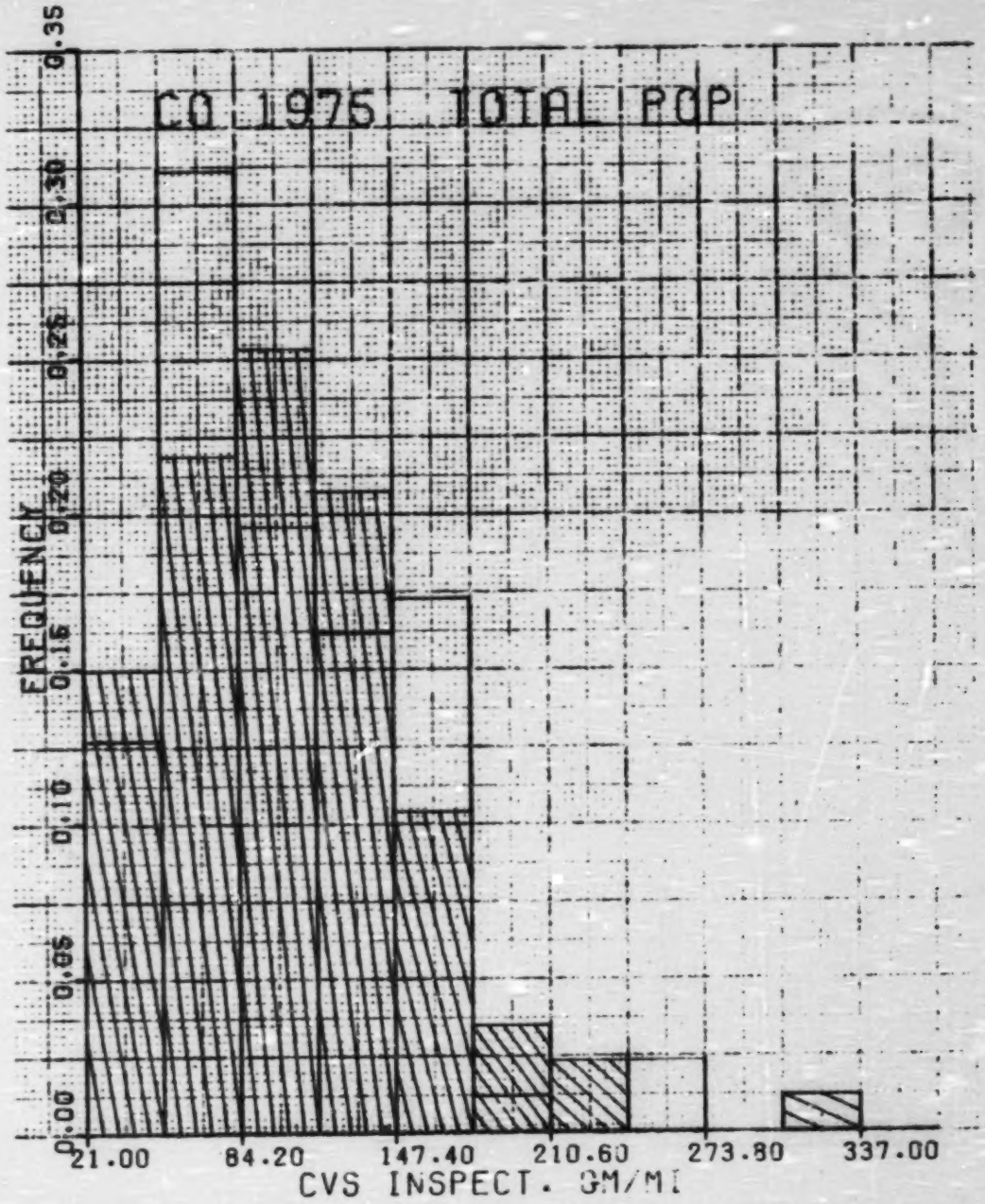

Figure 5-3 CO Histogram for Idle Inspection Pre and Post Deterioration for Total Population

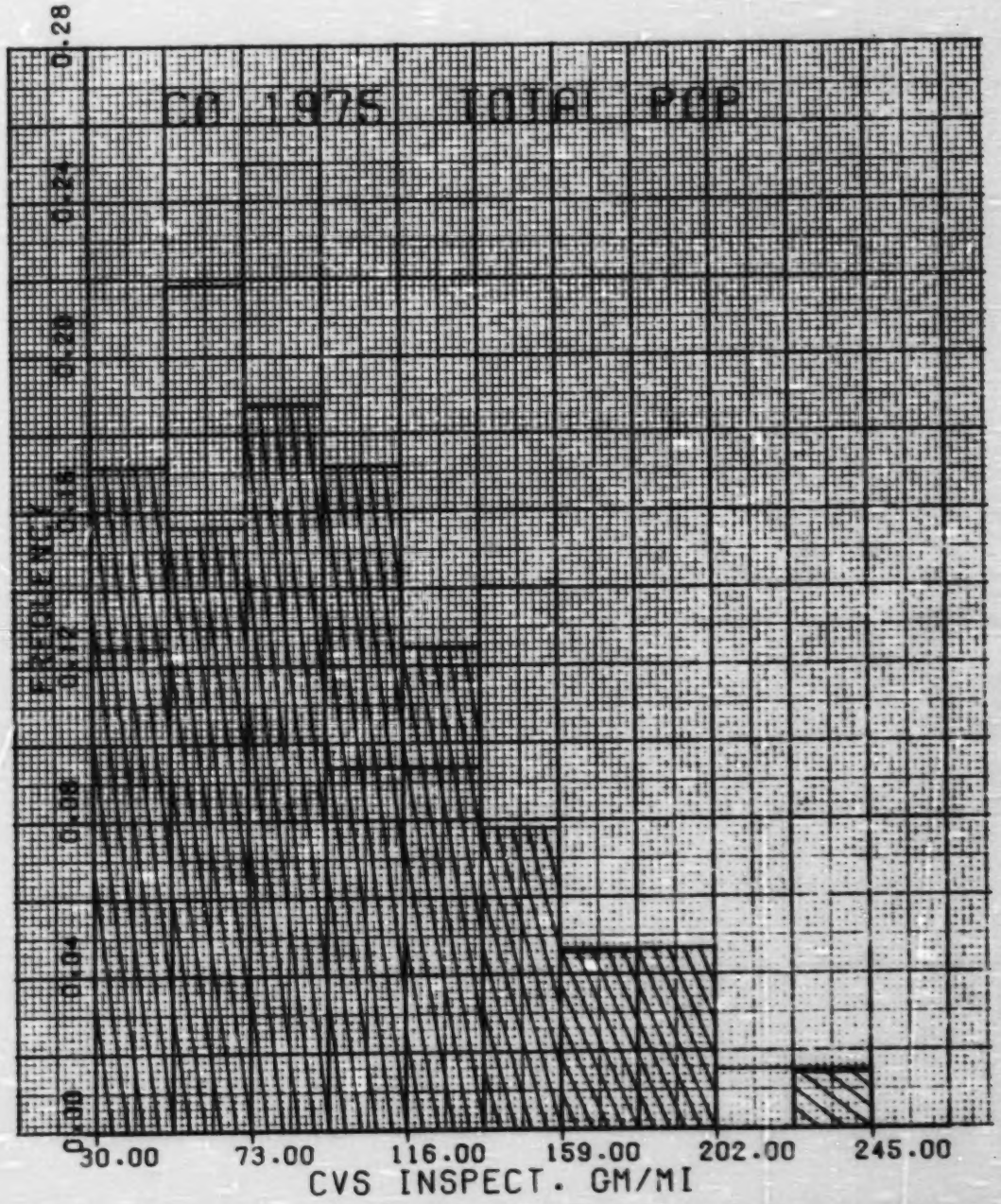

Figure 5-4 CO Histogram for Idle Inspection Pre and Post Deterioration with Unauthorized Maintenance Eliminated

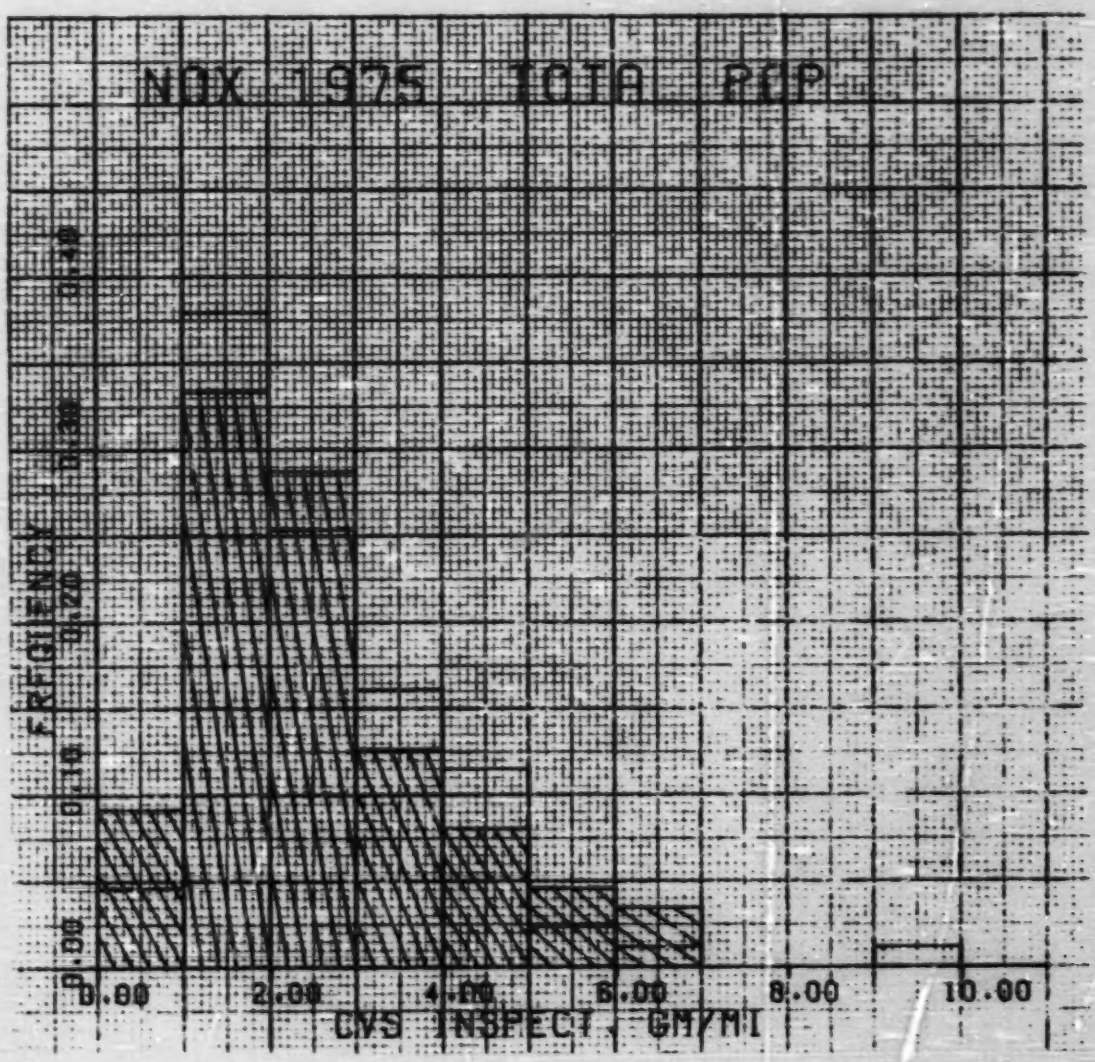

Figure 5-5 NOx Histogram for Idle Inspection Pre and Post Deterioration for Total Population

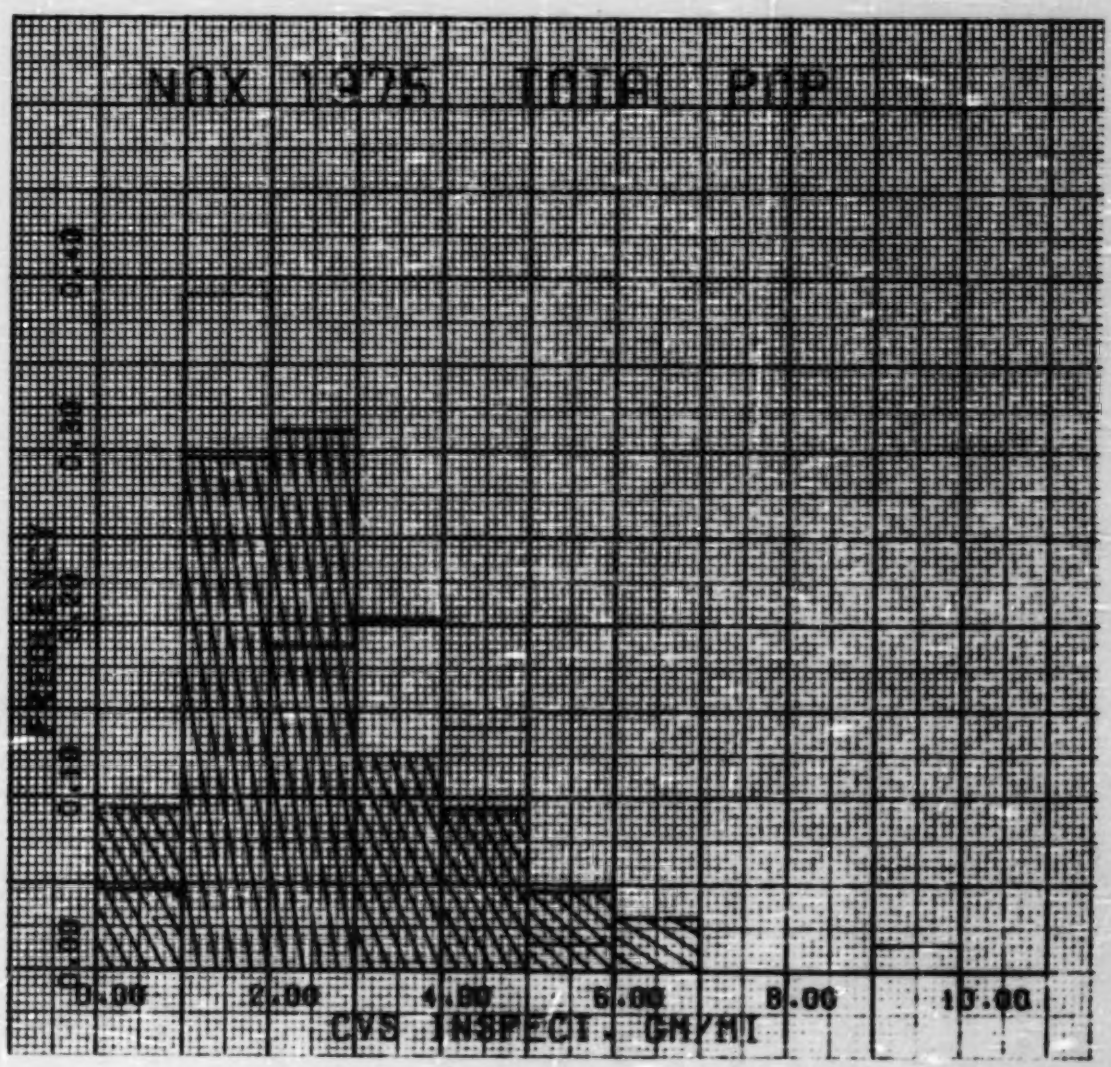

Figure 5-6 NOx Histogram for Idle Inspection Pre and Post Deterioration with Unauthorized Maintenance Eliminated

A further analysis was performed on the total vehicle population for the idle inspection regime to determine the impact of deterioration on pass/fail rates. Vehicles which passed the idle mode criteria prior to maintenance tended to remain in a good state of repair at the end of six months (the rejection rate of 36.8 percent is somewhat misleading because of the relatively small sample size). Vehicles which failed the idle test prior to maintenance, on the other hand, showed a decrease in the failure rates over the deterioration period. This apparent anomaly (one would expect the failure rate to rise over time) can not be fully explained with existing data. Potential explanation could include climatic changes and test procedures. These results are summarized in Tables 5-4 and 5-5 for the total population and unadjusted population, respectively. The impact of removing vehicles which had undergone unauthorized repair does not appear to have an impact in these trends, although again the sample size for "passed vehicles" is unfortunately small.

The results just presented, however, do not reveal the whole picture. Because of the great disparity between emission levels for precontrol (1967 and earlier) and controlled vehicles (1968 and later), it was decided to separate the vehicles into these two subgroups. Tables 5-6 and 5-7 present CVS mass emission data for this particular matrix. Precontrol vehicles emit significantly more pollutants than do the control vehicles, but the evidence implies that controlled vehicles deteriorate at a more rapid pace. In fact, HC emission increased significantly over the six month period. It should be noted, however, the relative small sample sizes in these cases may tend to bias the observed results.

TABLE 5-4

IDLE INSPECTION MODE FAILURE RATES FOR TOTAL POPULATION

	HC (PPM)	CO (%)	NO_x (PPM)	FAILED (NUMBER)	FAILED (%)
PASSED PRE-MAINTENANCE					
PRE-MAINTENANCE	502.32	3.64	111.42	0	0.0
POST-MAINTENANCE	597.47	2.53	112.32	3	15.8 (a)
POST- SIX MONTHS	651.53	3.53	82.11	7	36.8
SAMPLE SIZE = 19					
FAILED PRE-MAINTENANCE					
PRE-MAINTENANCE	945.29	6.42	82.11	68	100.0
POST-MAINTENANCE	749.88	4.23	85.26	55	30.9
POST-SIX MONTHS	822.72	4.49	98.65	45	66.2
SAMPLE SIZE = 68					

(a) Reflects difference between laboratory and garage procedures (i.e., some vehicles passing the laboratory inspection were failed and maintained at the garage).

TABLE 5-5

IDLE INSPECTION MODE FAILURE RATES WITH UNAUTHORIZED MAINTENANCE ELIMINATED

	HC (PPM)	CO (%)	NO_x (PPM)	FAILED (NUMBER)	FAILED (%)
PASSED PRE-MAINTENANCE					
PRE-MAINTENANCE	484.36	3.52	121.64	0	0.0
POST-MAINTENANCE	578.36	2.36	118.71	1	7.1 (a)
POST-SIX MONTHS	561.43	3.78	83.57	5	35.7
SAMPLE SIZE = 14					
FAILED PRE-MAINTENANCE					
PRE-MAINTENANCE	949.56	6.10	63.82	50	100.0
POST-MAINTENANCE	755.74	4.25	81.66	41	82.0
POST- SIX MONTHS	815.74	4.25	109.98	31	62.0
SAMPLE SIZE = 50					

(a) Reflects difference between laboratory and garage procedures (i.e., some vehicles passing the laboratory inspection were failed and maintained at at the garage).

TABLE 5-6

CVS EMISSIONS FOR IDLE INSPECTION PRECONTROL VEHICLES

MODE	PRE-DETERIORATION MEAN (GR/MI)	STD. DEV.	POST-DETERIORATION MEAN (GR/MI)	STD. DEV.	DIFFERENCE (GR/MI/ 1000 MI)	(GR/MI MONTH)	T-SCORE
HC	8.70	3.70	8.76	2.74	0.02	0.01	0.32
CO	123.70	43.55	129.63	52.57	1.48	1.00	0.40
NO_x	2.25	1.40	2.19	1.21	-0.01	-0.01	-0.24

SAMPLE SIZE = 49

UNAUTHORIZED MAINTENANCE ELIMINATED

HC	8.11	2.46	8.41	2.63	0.08	0.05	0.42
CO	117.44	43.24	121.49	44.04	1.00	0.69	0.33
NO_x	2.38	1.57	2.30	1.32	-0.02	-0.01	-0.18

SAMPLE SIZE = 37

TABLE 5-7

CVS EMISSIONS FOR IDLE INSPECTION CONTROLLED VEHICLES

MODE	PRE-DETERIORATION MEAN (GR/MI)	PRE-DETERIORATION STD. DEV.	POST-DETERIORATION MEAN (GR/MI)	POST-DETERIORATION STD. DEV.	DIFFERENCE (GR/MI 1000 MI)	DIFFERENCE (GR/MI/ MONTH)	T-SCORE
HC	4.79	1.74	5.88	4.89	0.27	0.18	1.11
CO	72.01	34.76	75.04	30.96	0.76	0.51	0.65
NO_x	3.04	1.30	2.99	1.52	-0.01	-0.01	-0.45
	SAMPLE SIZE = 38						
	UNAUTHORIZED MAINTENANCE ELIMINATED						
HC	4.83	1.90	6.23	5.74	0.34	0.24	0.94
CO	67.82	28.79	69.93	24.77	0.52	0.30	0.40
NO_x	2.98	1.11	2.94	1.49	-0.01	-0.01	-0.49
	SAMPLE SIZE = 27						

Regression and Statistical Analysis

One basic objective of this study was in identifing explanatory factors that might contribute to the observed rate of emission deterioration. Some of the potential forces influencing deterioration are listed below:

- Previous driving history (e.g., mileage accumulation)
- Climate
- Fuel characteristics
- Post-tune-up conditioning
- Unauthorized maintenance

In an attempt to evaluate these effects, a regression analysis was performed on the experimental data. Mileage accumulation over the period was selected as the primary variable of interest since the characteristics of the other listed variables posed service technical problems. The results of this preliminary regression analysis are given in Table 5-8. A cursory examination of these results reveals that mileage accumulation does not explain a significant component of the observed emission deterioration (maximum of four percent). Clearly, other forces were at work which will be examined at the end of the twelve month period.

While these results are not incouraging, it must be kept in mind that the measured emission deterioration rates, for the most part, were not statistically significant. That is, the actual rates must be assumed to be zero for lack of the necessary statistical support. An important question emerging from this discussion is - what level of emission deterioration will reveal statistically significant results over a given time period? In an attempt to answer this question an

TABLE 5-8

LINEAR LEAST SQUARES REGRESSIONS FOR IDLE INSPECTION DETERIORATION CVS EMISSIONS

VEHICLE TYPE	EMISSION TYPE		CONSTANT		COEFFICIENT			PERCENT DETERMINED
PRECONTROLLED	HC	=	-0.2906	+	0.00009664	X	OD	4.1
CONTROLLED	HC	=	-1.5590	+	0.0005814	X	OD	4.1
PRECONTROLLED	CO	=	5.798	+	0.00003711	X	OD	0.0
CONTROLLED	CO	=	-3.410	+	0.001413	X	OD	0.0
PRECONTROLLED	NO_x	=	-0.5230	-	0.00000128	X	OD	0.0
CONTROLLED	NO_x	=	-0.4500	+	0.00008659	X	OD	0.0

UNAUTHORIZED MAINTENANCE ELIMINATED

PRECONTROLLED	HC	=	0.0951	+	0.00005626	X	OD	4.0
CONTROLLED	HC	=	-1.6457	+	0.00064574	X	OD	4.0
PRECONTROLLED	CO	=	4.3479	-	9.00007935	X	OD	0.0
CONTROLLED	CO	=	-5.3702	+	0.00158867	X	OD	0.0
PRECONTROLLED	NO_x	=	-0.0897	+	0.00000295	X	OD	0.0
CONTROLLED	NO_x	=	-0.3441	+	0.00006464	X	OD	0.0

analysis was performed to determine what emission levels would be necessary for a significant deterioration to have occured. Furthermore, on an assumption that the deterioration was linear with time, an estimated length of deterioration was computed for the significant emission levels. The results of this analysis are summarized in Table 5-9 . They show that HC mass emissions require approximately seven months for significant deterioration and CO mass emissions between ten and fifteen months for significant deterioration. These observations appear consistent with the data presented in Table 5-3 (i.e., the T-score for HC (0.83) is closest to unity). Furthermore, they represent a return to approximately eighty percent of the "as received" state. The NOx mass emissions tend to decrease with time and will require nearly two years to achieve a statistically significant difference from the post-tuned condition. These post deterioration CVS emissions were then compared with the emissions before maintenance by means of a T-test. For precontrol vehicles, the significant post deterioration emissions were not significantly different from the emissions before maintenance. For controlled vehicles the evidence is not conclusive. HC emissions were not significantly different, and once unauthorized maintenance was eliminated,CO emissions were not significantly different.

Effects of Maintenance and Vehicle Characteristics on Deterioration

One key issure concerning the impact of deterioration involves the possible influences of maintenance and vehicle characteristics. The analysis evaluated the relationship between maintenance and deterioration by dividing the idle fleet into two subgroups, one containing those cars which had maintenance performed upon them

TABLE 5-9

IDLE INSPECTION EMISSION LEVELS TO ACHIEVE SIGNIFICANT DETERIORATION

MODE	PRE-MAINTENANCE	POST-DETERIORATION*	LENGTH OF DETERIORATION* (MONTHS)	T-SCORE
HC	8.18	7.57	6.8	0.843
CO	111.80	108.66	9.7	0.400
NO_x	2.64	2.39	21.3	0.795
	SAMPLE SIZE = 87			
	UNAUTHORIZED MAINTENANCE ELIMINATED			
HC	7.73	7.37	5.1	0.467
CO	103.95	104.46	14.8	0.065
NO_x	2.70	2.38	25.1	0.735
	SAMPLE SIZE = 64			

*ESTIMATED

(failed garage inspection), the other group containing those cars which passed the garage inspection and thus had no maintenance performed. Tables 5-10 and 5-11 show how these two groups deteriorated. Precontrol vehicles reveal very little deterioration in either subgroup, however, those vehicles which received maintenance showed some deterioration of CO mass emissions. Control vehicles did go through significant deterioration during the six month period.

Tables 5-12 through 5-15 summarize deterioration results for the idle inspection and maintenance vehicles divided into subgroups by control type (pre-1968, post-1967) and by engine size (less than 200 cubic inches, greater than or equal to 200 cubic inches). Because of the small sample sizes resulting from this partitioning scheme the deterioration factors are not statistically significant except for HC mass emissions for controlled vehicles with large engines.

5.2 MANDATORY ENGINE MAINTENANCE

An evaluation of mandatory engine maintenance was conducted by comparing the emissions from a set of vehicles drawn from the general population with the same vehicles after they had received engine maintenance (for detailed analysis see Volume IV, Section 6.0). The results of this analysis are summarized in Table 5-16 for the 78 cars which went through the deterioration study and for the 59 vehicles of this fleet that did not receive unauthorized maintenance.

After the maintenance these cars were returned to their owners for a period of six months. The procedure was identical to the idle test program. The vehicles were then recalled and retested. The results of these tests for the CVS mass emissions are detailed in Table 5-17. The HC emissions showed significant increases from

TABLE 5-10

ANALYSIS OF IDLE INSPECTION AND MAINTENANCE REGIME FOR TOTAL POPULATION

MODE	RECEIVED MAINTENANCE				NO MAINTENANCE			
	PRECONTROL		CONTROLLED		PRECONTROL		CONTROLLED	
	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
				PRE-MAINTENANCE				
HC	10.68	5.82	7.45	6.68	7.99	2.50	4.48	0.89
CO	137.57	44.19	97.75	57.79	117.23	41.66	74.51	39.63
NO_x	2.11	0.95	2.75	1.55	2.69	1.77	3.47	0.97
				POST-MAINTENANCE				
HC	9.23	4.37	4.95	2.04	7.99	2.50	4.48	0.89
CO	128.54	45.05	70.70	32.75	117.23	41.66	74.51	39.63
NO_x	1.92	0.95	2.82	1.41	2.69	1.77	3.47	0.97
				POST-DETERIORATION				
HC	9.48	2.74	5.26	2.46	7.79	2.48	7.06	7.70
CO	13°.01	57.34	75.80	30.96	117.11	43.66	73.59	32.18
NO_x	1.96	1.15	2.82	1.48	2.49	1.26	3.32	1.60
SAMPLE SIZES	(28)		(25)		(21)		(13)	

TABLE 5-11

ANALYSIS OF IDLE INSPECTION AND MAINTENANCE REGIME WITH UNAUTHORIZED MAINTENANCE ELIMINATED

MODE	RECEIVED MAINTENANCE				NO MAINTENANCE			
	PRECONTROL		CONTROLLED		PRECONTROL		CONTROLLED	
	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
PRE-MAINTENANCE								
HC	10.32	5.97	6.58	2.98	7.95	2.70	4.39	0.91
CO	129.92	38.33	86.31	31.60	114.48	44.72	66.13	28.84
NO_x	2.25	1.01	2.58	1.10	2.86	1.93	3.43	0.81
POST-MAINTENANCE								
HC	8.25	2.31	5.14	2.33	7.95	2.70	4.39	0.91
CO	119.95	42.94	68.98	29.65	114.48	44.72	66.13	28.84
NO_x	1.97	1.08	2.68	1.21	2.86	1.93	3.43	0.81
POST-DETERIORATION								
HC	9.12	2.62	5.43	2.90	7.58	2.48	7.39	8.39
CO	129.21	40.95	71.54	23.73	112.42	47.02	67.58	27.20
NO_x	1.98	1.28	2.80	1.56	2.68	1.30	3.14	1.44
SAMPLE SIZES	(20)		(16)		(17)		(11)	

TABLE 5-12

IDLE INSPECTION CVS EMISSIONS FOR PRECONTROL VEHICLES WITH SMALL ENGINES

MODE	PRE-DETERIORATION MEAN (GR/MI)	DEV.	POST-DETERIORATION MEAN (GR/MI)	DEV.	DIFFERENCE (GR/MI/ 1000 MI)	(GR/MI/ MONTH)	T-SCORE
HC	8.30	3.02	8.43	3.76	0.03	0.02	-0.13
CO	103.84	25.70	100.18	35.02	-0.93	-0.62	-0.51
NO_x	1.66	0.56	1.89	0.81	0.06	0.04	0.46

SAMPLE SIZE = 9

UNAUTHORIZED MAINTENANCE ELIMINATED

HC	7.63	2.30	7.79	4.09	0.04	0.03	-0.23
CO	97.84	21.47	93.67	36.56	-1.04	-0.71	-0.56
NO_x	1.77	0.60	2.09	0.82	0.08	0.05	0.61

SAMPLE SIZE = 7

TABLE 5-13

IDLE INSPECTION CVS EMISSIONS FOR PRECONTROL VEHICLES WITH LARGE ENGINES

MODE	PRE-DETERIORATION MEAN (GR/MI)	PRE-DETERIORATION STD. DEV.	POST-DETERIORATION MEAN (GR/MI)	POST-DETERIORATION STD. DEV.	DIFFERENCE (GR/MI 1000 MI)	DIFFERENCE (GR/MI/ MONTH)	T-SCORE
HC	8.79	3.87	8.83	2.51	0.01	0.01	0.47
CO	128.15	45.70	136.25	53.89	2.02	1.36	0.68
NO_x	2.38	1.50	2.26	1.28	-0.03	-0.02	-0.40

SAMPLE SIZE = 40

UNAUTHORIZED MAINTENANCE ELIMINATED

HC	8.22	2.52	8.56	2.24	0.08	0.06	0.69
CO	122.00	45.95	127.99	43.59	1.48	1.01	0.64
NO_x	2.52	1.70	2.35	1.42	-0.04	-0.03	-0.37

SAMPLE SIZE = 30

TABLE 5-14

IDLE INSPECTION CVS EMISSIONS FOR CONTROLLED VEHICLES WITH SMALL ENGINES

MODE	PRE-DETERIORATION MEAN (GR/MI)	PRE-DETERIORATION STD. DEV.	POST-DETERIORATION MEAN (GR/MI)	POST-DETERIORATION STD. DEV.	DIFFERENCE (GR/MI/ 1000 MI)	DIFFERENCE (GR/MI/ MONTH)	T-SCORE
HC	4.88	2.42	4.40	1.40	-0.12	-0.08	-0.65
CO	68.97	36.66	68.69	33.00	-0.07	-0.05	-0.07
NO_x	2.35	1.10	2.25	1.14	-0.02	-0.02	-0.29
	SAMPLE SIZE = 15						
	UNAUTHORIZED MAINTENANCE ELIMINATED						
HC	4.80	2.58	4.23	1.43	-0.14	-0.10	-0.73
CO	61.48	31.00	60.74	23.04	-0.18	-0.12	-0.08
NO_x	2.54	1.05	2.42	1.13	-0.03	-0.02	-0.37
	SAMPLE SIZE = 13						

TABLE 5-15

IDLE INSPECTION CVS EMISSIONS FOR CONTROLLED VEHICLES WITH LARGE ENGINES

MODE	PRE-DETERIORATION MEAN (GR/MI)	PRE-DETERIORATION STD. DEV.	POST-DETERIORATION MEAN (GR/MI)	POST-DETERIORATION STD. DEV.	DIFFERENCE (GR/MI/ 1000 MI)	DIFFERENCE (GR/MI/ MONTH)	T-SCORE.
HC	4.73	1.16	6.84	6.04	0.53	0.36	1.74
CO	73.99	34.15	79.18	29.55	1.30	0.87	0.78
NO_x	3.50	1.23	3.47	1.56	0.01	0.00	0.42

SAMPLE SIZE = 23

UNAUTHORIZED MAINTENANCE ELIMINATED

HC	4.86	1.03	8.08	7.50	0.80	0.55	1.73
CO	73.71	26.34	78.46	23.95	1.18	0.80	0.54
NO_x	3.39	1.03	3.43	1.66	0.01	0.01	-0.36

SAMPLE SIZE = 14

TABLE 5-16

MANDATORY MAINTENANCE CVS EMISSIONS PRE AND POST MAINTENANCE

MODE	PRE-MAINTENANCE MEAN (GR/MI)	STD. DEV.	POST-MAINTENANCE MEAN (GR/MI)	STD. DEV.	DIFFERENCE (% REDUCTION)	T-SCORE
HC	7.59	4.49	6.68	2.96	12.0	1.30
CO	108.65	49.99	101.97	46.76	6.1	0.89
NO_x	2.53	1.40	2.34	1.31	7.5	0.96

SAMPLE SIZE = 78

UNAUTHORIZED MAINTENANCE ELIMINATED

HC	7.20	4.02	6.55	2.75	9.0	0.81
CO	104.85	46.40	101.77	45.83	2.9	0.33
NO_x	2.62	1.45	2.45	1.36	6.5	0.80

SAMPLE SIZE = 59

TABLE 5-17

MANDATORY MAINTENANCE CVS EMISSIONS PRE AND POST DETERIORATION

MODE	PRE-DETERIORATION MEAN (GR/MI)	PRE-DETERIORATION STD. DEV.	POST-DETERIORATION MEAN (GR/MI)	POST-DETERIORATION STD. DEV.	DIFFERENCE (GR/MI/ 1000 MI)	DIFFERENCE (GR/MI/ MONTH)	T-SCORE
HC	6.68	2.96	9.24	9.10	0.64	0.43	1.65
CO	101.97	46.76	107.39	57.31	1.35	0.91	0.19
NO_x	2.34	1.31	2.35	1.43	0.00	0.00	-0.32

SAMPLE SIZE = 78

UNAUTHORIZED MAINTENANCE ELIMINATED

HC	6.55	2.75	9.38	10.00	0.70	0.48	1.48
CO	101.77	45.83	107.04	54.29	1.30	0.84	0.35
NO_x	2.45	1.36	2.42	1.36	-0.01	-0.00	-0.30

SAMPLE SIZE = 59

6.68 gm/mi to 9.24 gm/mi. The T-score of 1.65 is extremely strong which indicates the statistical significance of the deterioration factors for HC. CO emissions showed no significant increases. Reported NOx emissions were also not statistically significant. Again, the reference point for conductiong the statistical analysis was the post-tuned state.

These results are illustrated within the histogram frequency plots of Figures 5-7 through 5-12. These plots reveal that both pre-deterioration (blank bars) and post deterioration results (hatched bars) are log-normally distributed for HC, CO, and NOx emissions. There is a general trend of a right shift of the post deterioration distributions with respect to the pre deterioration distributions for the three emission types. Furthermore, the statistically significant increase in HC emissions is explained by the small group of vehicles for which the HC emissions have increased dramatically after six months (the result of incipient misfire).

Analyzing the vehicle population as a whole assumes some degree of homogeneity. This assumption is useful, but for policy analysis it became necessary to classify the vehicle population by age groupings control type.* This partitioning reaps immediate benefits in the form of Tables 5-18 and 5-19. Precontrol vehicles tended to deteriorate to a much greater extent than did the controlled vehicles. HC emissions for precontrol vehicles showed an extremely significant increase from 9.44 gm/mi to 15.90 gm/mi. For those cars which did

* Results presented in Volume IV confirm the fact that emission levels from pre-1968 vehicles are indeed different from post-1967 vehicles and must be treated separately, consequently these two classes.

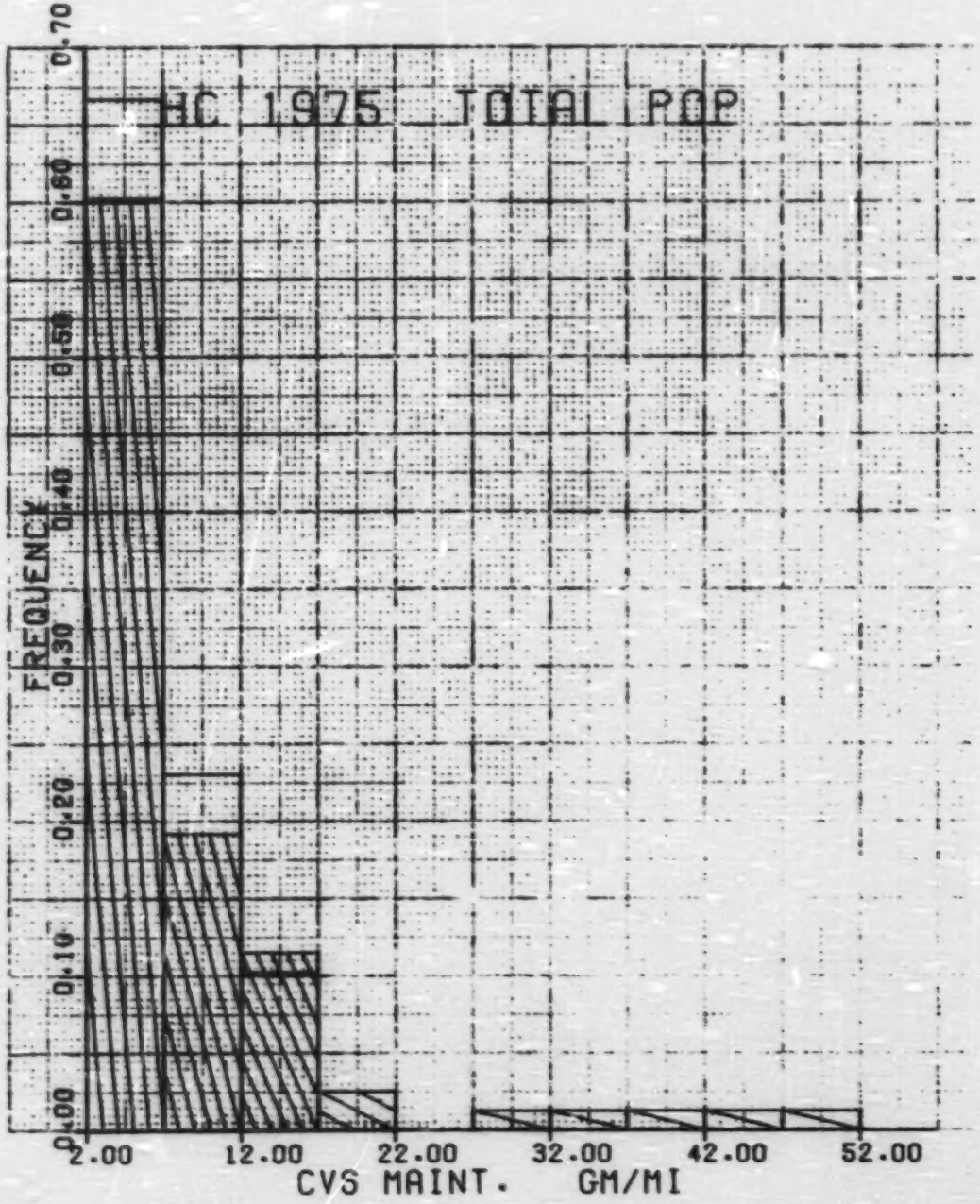

Figure 5-7 HC Histogram for Mandatory Maintenance Pre and Post Deterioration for Total Population

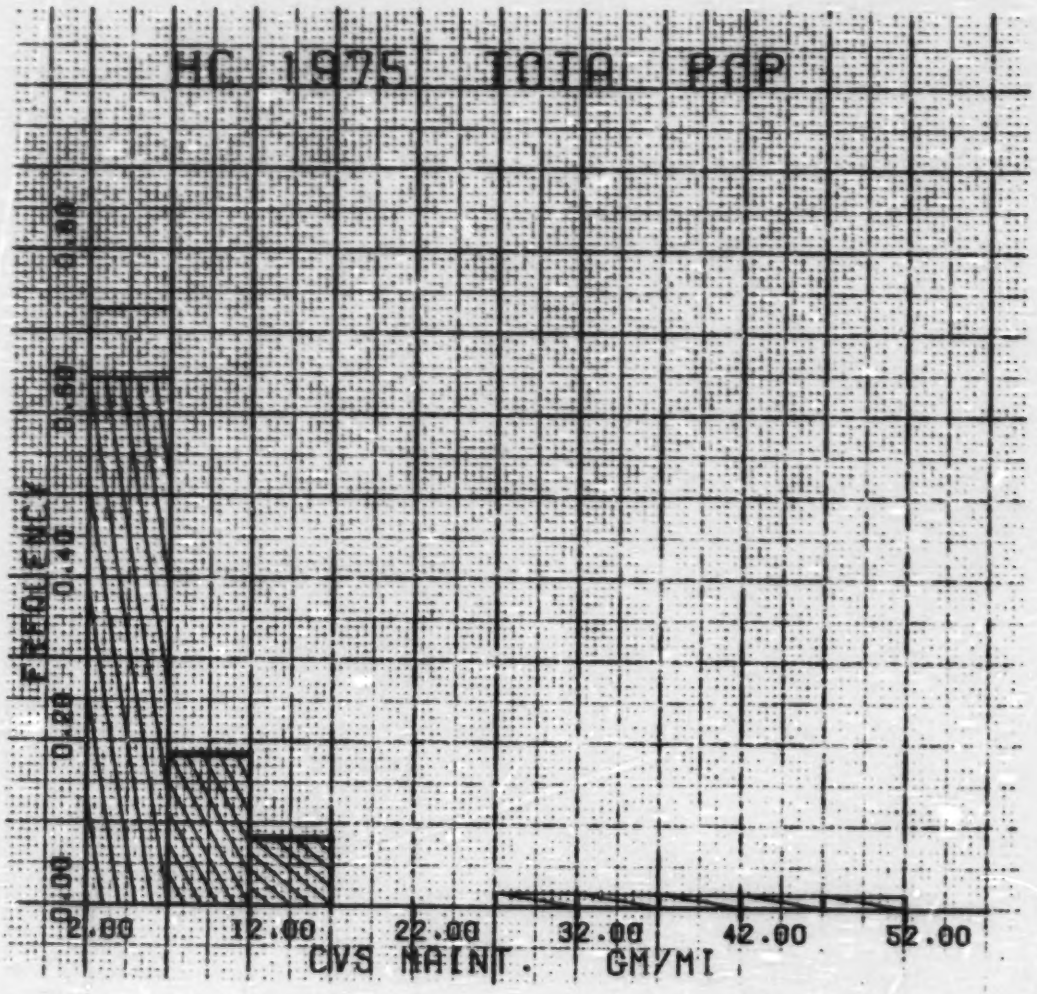

Figure 5-8 HC Histogram for Mandatory Maintenance Pre and Post Deterioration with Unauthorized Maintenance Eliminated

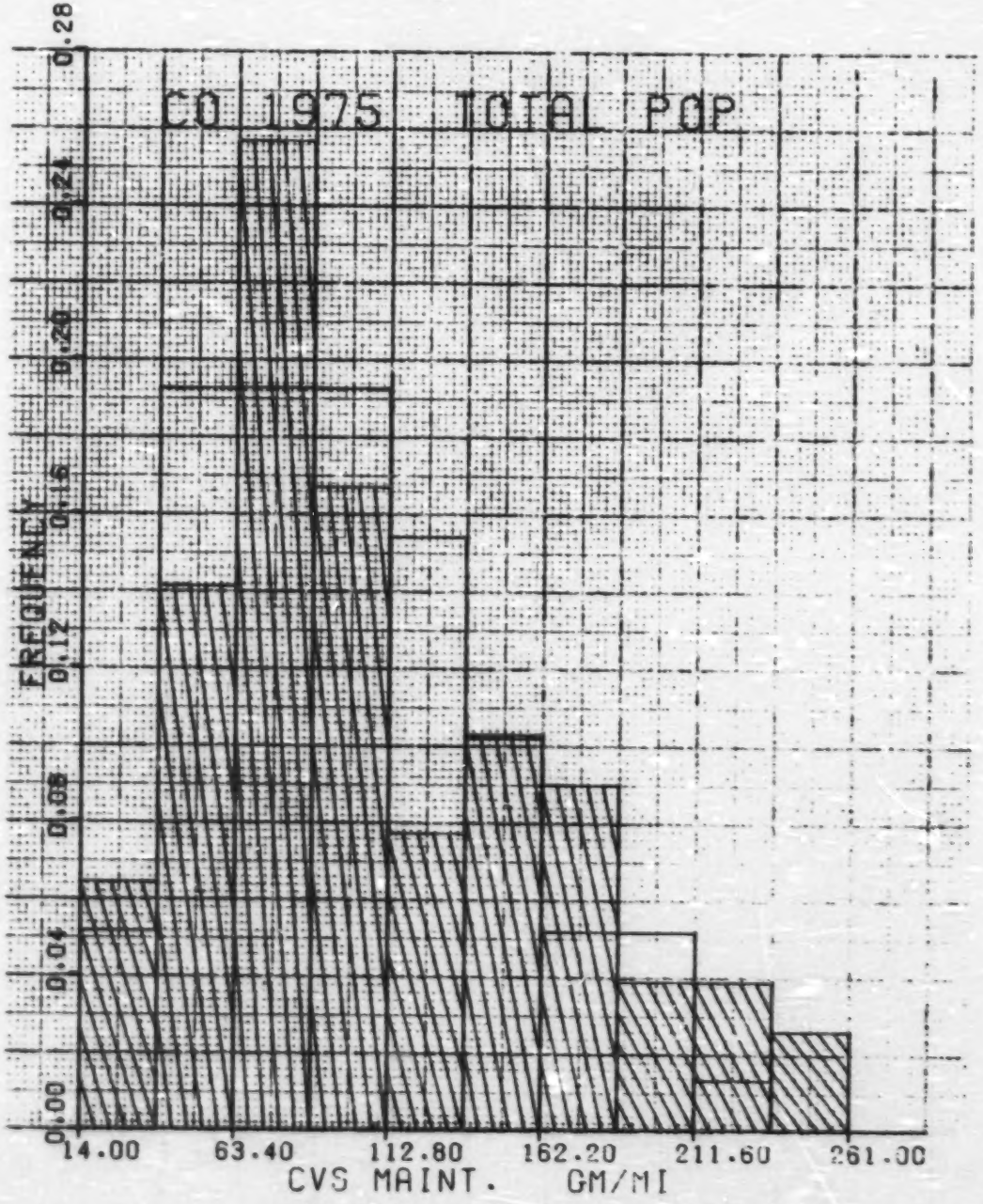

Figure 5-9 CO Histogram for Mandatory Maintenance Pre and Post Deterioration for Total Population

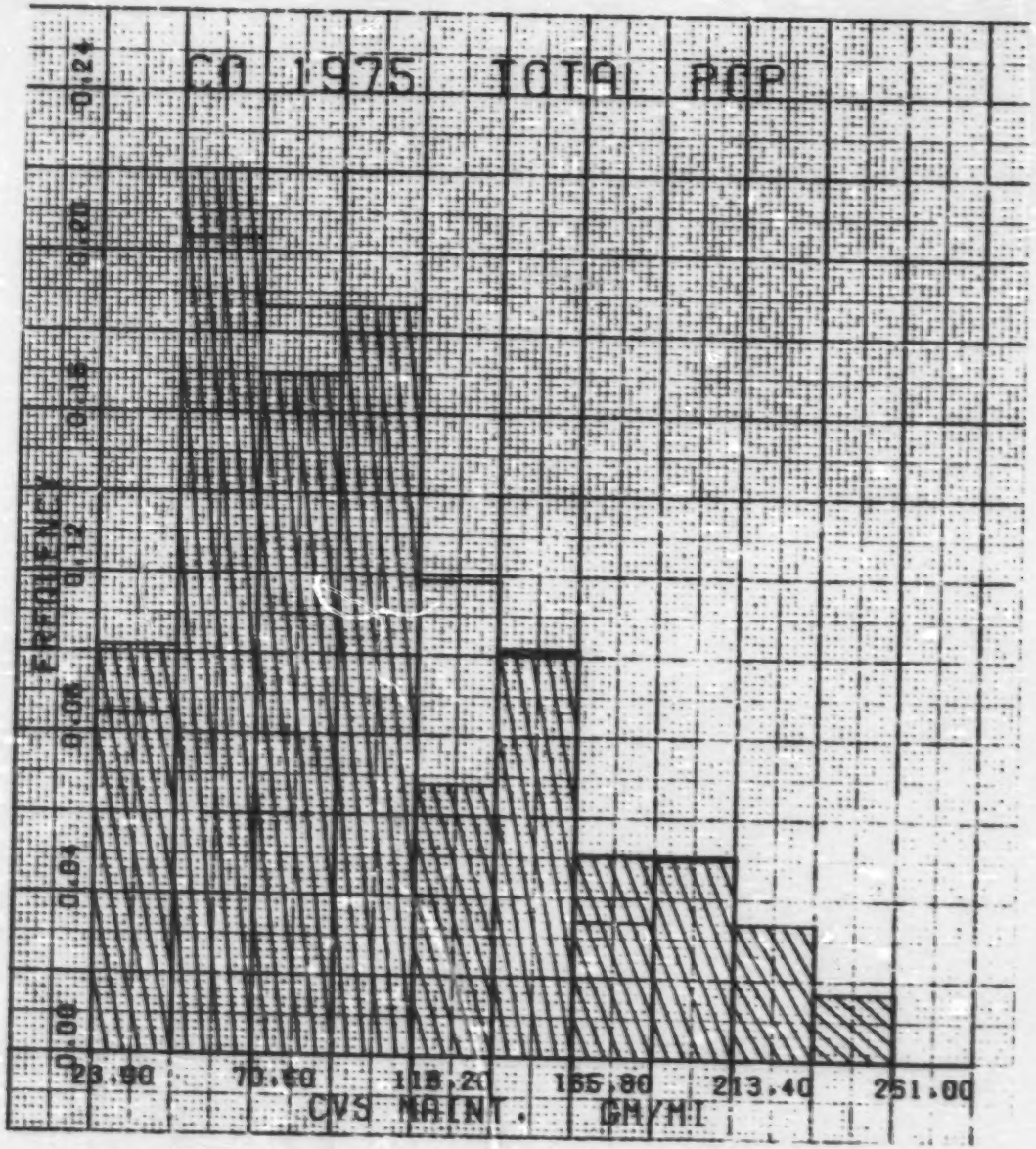

Figure 5-10 CO Histogram for Mandatory Maintenance Pre and Post Deterioration with Unauthorized Maintenance Eliminated

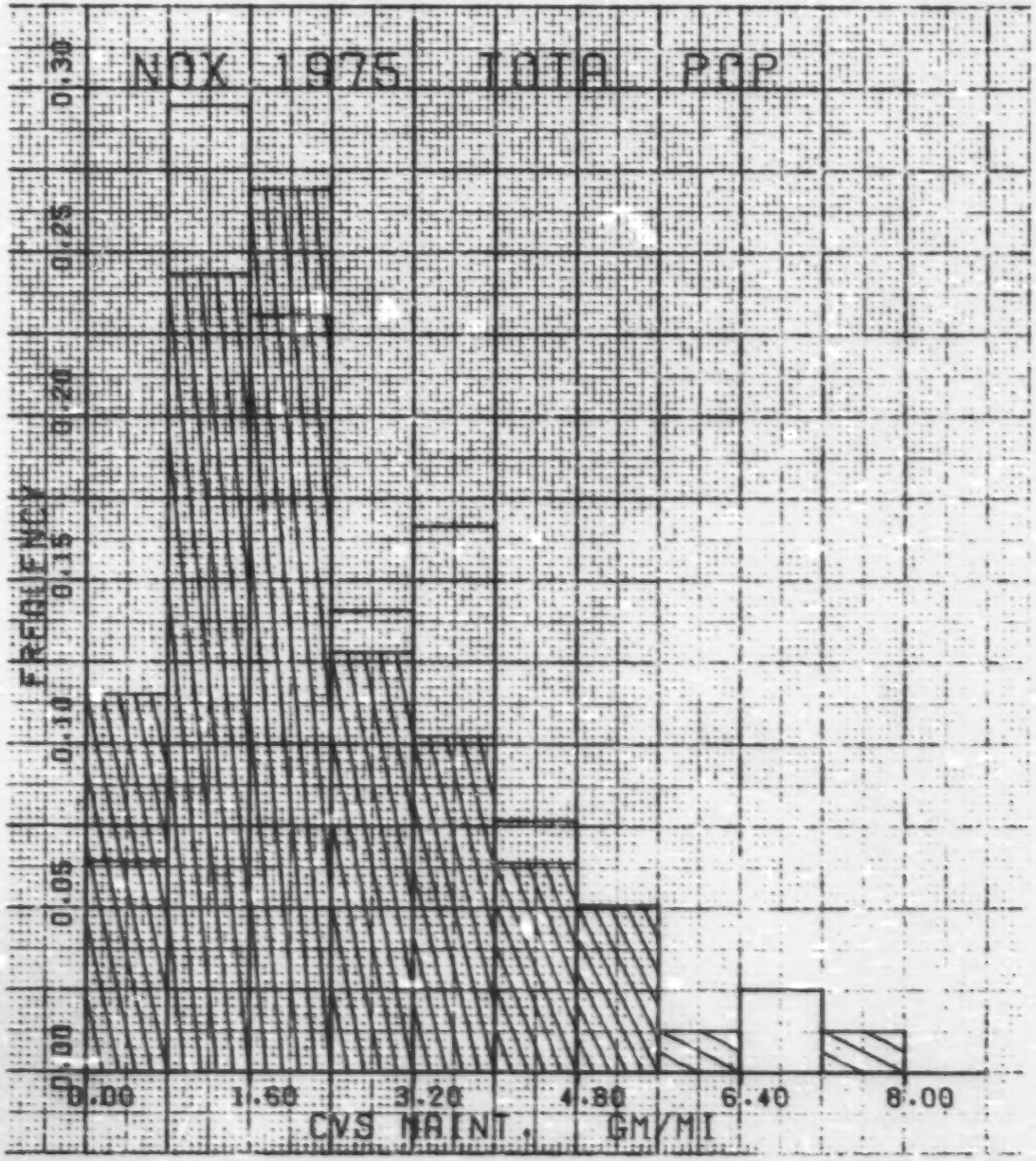

Figure 5-11 NOx Histogram for Mandatory Maintenance Pre and Post Deterioration for Total Population

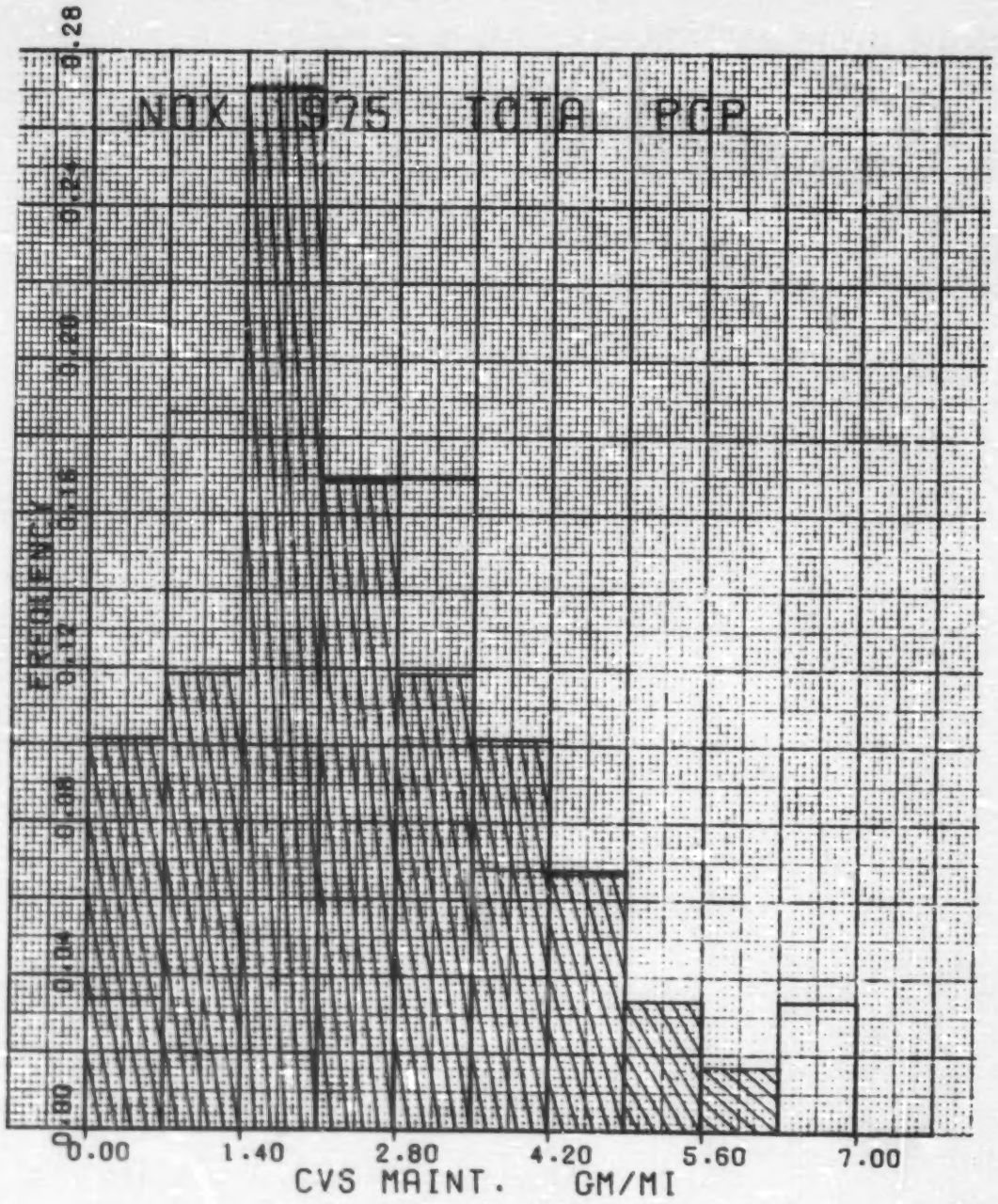

Figure 5-12 NOx Histogram for Mandatory Maintenance Pre and Post Deterioration with Unauthorized Maintenance Eliminated

TABLE 5-18

CVS EMISSIONS FOR MANDATORY MAINTENANCE PRECONTROL VEHICLES

MODE	PRE-DETERIORATION MEAN (GM/MI)	PRE-DETERIORATION STD. DEV.	POST-DETERIORATION MEAN (GM/MI)	POST-DETERIORATION STD. DEV.	DIFFERENCE (GM/MI/ 1000 MI)	DIFFERENCE (GM/MI/ MONTH)	T-SCORE
HC	9.44	2.53	15.90	12.07	1.61	1.09	2.53
CO	143.70	42.38	156.97	50.31	3.42	2.30	0.65
NO_x	1.80	1.12	1.59	1.17	-0.05	-0.03	-0.92

SAMPLE SIZE = 23

UNAUTHORIZED MAINTENANCE ELIMINATED

HC	8.42	2.70	17.38	15.16	2.09	1.43	1.95
CO	143.28	47.83	153.28	51.11	2.47	1.69	0.32
NO_x	2.05	1.30	1.83	1.39	-0.05	-0.04	-0.62

SAMPLE SIZE = 14

TABLE 5-19

CVS EMISSIONS FOR MANDATORY MAINTENANCE CONTROLLED VEHICLES

MODE	PRE-DETERIORATION MEAN (GM/MI)	PRE-DETERIORATION STD. DEV.	POST-DETERIORATION MEAN (GM/MI)	POST-DETERIORATION STD. DEV.	DIFFERENCE (GM/MI 1000 MI)	DIFFERENCE (GM/MI/ MONTH)	T-SCORE
HC	5.52	2.29	6.46	5.64	0.23	0.16	0.69
CO	84.70	36.82	86.66	46.56	0.49	0.33	-0.08
NO_x	2.57	1.32	2.67	1.42	0.03	0.02	0.28
	SAMPLE SIZE = 55						
	UNAUTHORIZED MAINTENANCE ELIMINATED						
HC	5.81	2.33	6.89	6.11	0.27	0.18	0.65
CO	88.85	37.06	92.66	47.13	0.94	0.64	0.27
NO_x	2.57	1.37	2.60	1.31	0.01	0.01	0.09
	SAMPLE SIZE = 45						

not have unauthorized maintenance performed on them the increase was even more dramatic from 8.42 gm/mi to 17.38 gm/mi. The T-scores are also extremely strong at 2.53 and 1.95, respectively. The primary causes of this increase are the high incidence of ignition misfire and the relatively small sample size. HC emissions for controlled vehicles showed increases but these were not statistically significant. CO emission for both groups increased insignificantly and NOx emissions wandered insignificantly.

In general, the deterioration results for the mandatory maintenance fleet showed greater variability expecially in the case of HC, than for the idle inspection fleet. These trends can be directly associated with the detection of incipient misfire in the pre controlled group, the attrition of lower emitting vehicles and the somewhat newer car mix. The relatively high incidence of unauthorized maintenance associated with the mandatory maintenance fleet can not be readily explained. Typically, all vehicles in this fleet were tuned-up to manufacturer's specifications. One possibility may involve the climatic impact on engine driveability. The original post maintenance measurements were made during autumn while the six month test occured in the spring. The reported deterioration results may reflect the impact of a "winter" maintenance tune-up.